UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
WASHINGTON, D. C.
H. H. BENNETT, CHIEF

ADVANCE REPORT

on the

SEDIMENTATION SURVEY OF LAKE LEE

MONROE, NORTH CAROLINA

May 23 - June 14, 1933

by

Mark P. Connaughton and Jack L. Hough

Sedimentation Division
Office of Research
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NORTH CAROLINA AGRICULTURAL EXPERIMENT STATION
Raleigh, N. C.
I. O. Schaub, Acting Director

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ABSTRACT

The sedimentation survey of Lake Lee was made as part of a Nation-wide study of rates and causes of reservoir silting, especially as influenced by soil erosion and land use.

Lake Lee, the municipal water supply for Monroe, N. C., is a channel-type 821-acre-foot reservoir on Richardson Creek, a minor tributary of the Peedee River. The 50.5 square-mile drainage basin of Lake Lee lies in the Piedmont upland and is characterized by gently rolling topography and silt-loam soils developed on slate and associated volcanic rocks. The area is now undergoing slight to moderate sheet erosion and some minor gullying. About 45 percent of the area is cropland, 9 percent is open pasture, and 46 percent is woodland of which one-fifth is pastured. The principal crops are small grains, lespedeza, cotton, and corn. Most of the land has probably been cultivated during one of more periods within the last 200 years.

Most of the reservoir sediment is fine silt and clay, there being but little increase in grain size toward the heads of the two main arms. Absence of delta deposits indicates the lack of sources of coarse-grained sediment in the drainage area. Laboratory studies of eight samples of reservoir sediment showed average median diameters of 3 to 8 microns and an average dry weight of 62 pounds per cubic foot. The average sediment thickness in the reservoir from the dam to points about a half mile below the respective heads of backwater is about 2 feet. An attempt is made to correlate the sediment distribution with underflow of sediment-laden waters, an occurrence of which was observed during the survey. The greater part of the sediment has probably originated from sheet erosion of the cultivated upland, but an appreciable amount may be derived from gullying associated with abandoned, or in some cases recent, roadways.

The survey revealed that 169 acre-feet (272,653 cubic yards) of sediment had accumulated in the reservoir at an average rate of about 20.6 cubic feet annually per acre of drainage area, entailing an annual storage loss of 1.85 percent, or a total of 20.6 percent to the date of this survey. Strikingly different rates of sediment accumulation in the two arms of the reservoir were revealed. An attempt is made to correlate this difference with characteristics of the drainage area and reservoir.

The extremely high rate of silting revealed by the survey points to an urgent need for application of proper soil-conserving measures on agricultural land in the drainage area as well as some measure of treatment on modern and abandoned roadways. Proper planning for a program of sediment control could best be carried out in cooperation with the Brown Creek Soil Conservation District.

INTRODUCTION

This report is one of a series of advance reports on sedimentation surveys of reservoirs throughout the United States, made by the Reservoir Section of the Sedimentation Division, Soil Conservation Service. Each reservoir survey is a part of a Nation-wide study of the condition of American reservoirs with respect to storage reduction by sedimentation. The ultimate objective of these studies is to determine rates and causes of reservoir sedimentation, in order to derive a practical index to (1) the useful-life expectancy of existing or contemplated reservoirs, and (2) differences and changes in regional erosion conditions as influenced both by natural factors and by land use.

The survey of Lake Lee was made during the period May 23 to June 14, 1938. The survey party consisted of Leland H. Barnes, chief of party, Mark P. Connaughton, party geologist, Alvin T. Talley, and Joseph Meisler. Jack L. Hough assisted during part of the survey. Preliminary data were secured and arrangements for the survey made by Alexis N. Garin, of the Conservation Economics Division, and Carl B. Brown, of the Reservoir Section, Sedimentation Division. Studies of the lake sediments and an inspection of the drainage area were made by the writers. Members of the staff of the Soil Conservation Service C.C.C. camp NC-16 at Monroe gave valuable assistance in the compilation of data on the drainage area.

Volume-weight determinations of the sediment samples were made by Jack L. Hough in the laboratories of the city filtration plant at High Point, N. C. Laboratory facilities were made available through the courtesy of the city of High Point.

Mechanical analyses of the sediment samples and of several representative soil samples were made by Richard G. Grassy in the laboratory of the Sedimentation Division at Greenville, S. C.

The cooperation and assistance of the Monroe city officials, particularly W. L. Burdette, city manager, and Geo. W. Tucker, superintendent of the water and light department, greatly facilitated the survey. Office space, materials needed in the setting of

permanent survey markers, and information on the construction and cost of the reservoir were supplied by the city. Robert Browning, in charge of the filter plant, and Henry Meyers, operator of boating and fishing concessions on Lake Lee, furnished much valuable information and cooperation.

G. W. Forester, head of the Department of Economics and Rural Sociology of the University of North Carolina, advised and aided in economic studies related to the various reservoir-silting investigations carried out in North Carolina during the spring of 1938.

GENERAL INFORMATION

Location. (fig. 1):

State: North Carolina.

County: Union.

Distance and direction from nearest city: The dam is 2 miles east of Monroe, N. C.

Drainage and backwater: Richardson Creek, which flows 14 1/2 miles northeastward from the dam to join the Rocky River, a tributary of the Peedee.

Ownership: City of Monroe.

Purposes served: (1) Municipal water supply; (2) recreation.

Description of dam.

The dam is a gravity-type, concrete structure with an overall length of 450 feet, and a maximum height of 30.5 feet above the stream bed. The spillway section is 420 feet long and 22.5 feet above the stream bed, or 489.90 feet above sea level.[1] The upstream face has a 1:1 slope, and the downstream face of the spillway has an ogee section.

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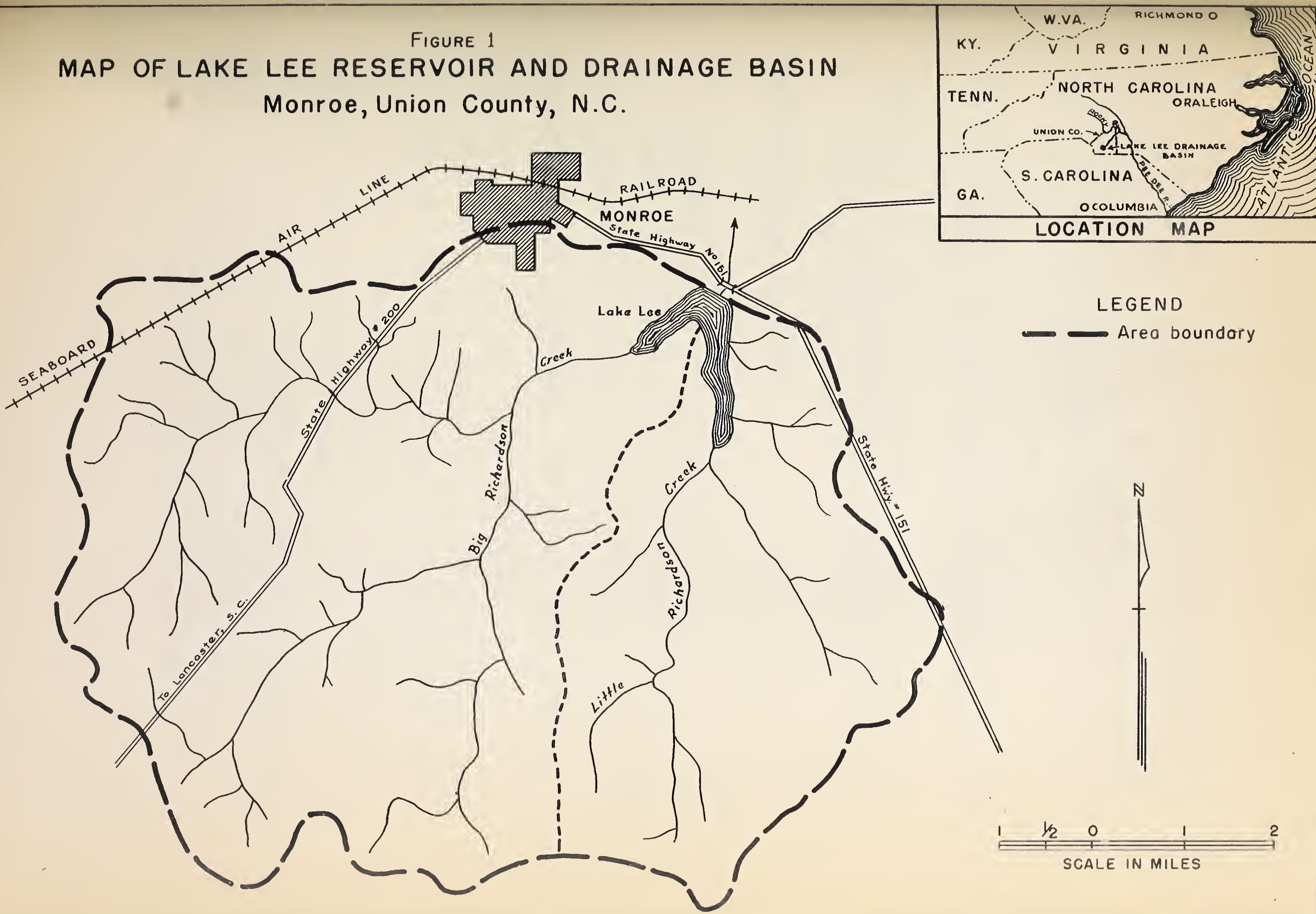
[1]Determined by a level traverse from United States Coast & Geodetic Survey bench mark No. 074-1935, located on the highway bridge over Richardson Creek a short distance below the dam. An assumed elevation of 100 feet was used in the survey of the lake.

Figure 1

MAP OF LAKE LEE RESERVOIR AND DRAINAGE BASIN

Monroe, Union County, N.C.



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An outlet, 36 inches in diameter, controlled by a "blow-off" valve, is located in the base of the dam near the deepest part of the original stream channel. This valve is opened during abnormal flood flows in an attempt to scour out sediment deposits adjacent to the outlet. Three 16-inch intakes located at 4, 10, and 20 feet, respectively, below spillway connect with the city pipe line, but so far only the upper opening has been used.

The total cost of the reservoir was $325,000.

Period of storage: Date storage began: April 1927. Average date of survey: June 1938. Total age of reservoir to date of survey: 11.2 years.

Length of lake: (Original and present, from dam to head of backwater) On Big Richardson Creek, 1.47 miles; on Little Richardson Creek, 1.62 miles. Distance from dam to junction of the two arms, 0.2 mile.

Area of lake at crest stage:

	Acres
Original	105.5
Present	104.8
Reduction	0.7

Storage capacity to crest level (Determined by this survey):

	Acre-feet	
Original	821	(267,522,350 gals.)
Present	652	(212,454,200 gals.)
Reduction by sedimentation	169	(55,068,650 gals.)

General character of reservoir basin.

The outline of the reservoir basin is shown in figure 2 (following p. 23). Water is impounded on the flood plains of Big Richardson and Little Richardson Creeks to within about 1/3 mile of the heads of backwater on the two arms, but above those points is confined to the stream channels. The valley sides adjacent to the basin are predominantly of gentle slope and extend down to an almost

flat flood plain. In the lower part of the lake the original flood-plain surface is submerged to an average depth of 10 feet. The maximum depth of the original stream channel below the flood-plain surface is 10.5 feet. For the lake basin as a whole the average width of the flood plain is about 340 feet. The submerged stream channels are gently meandering. The average gradient of the stream bed is 17.3 feet per mile in the Big Richardson arm and 14.8 feet per mile in the Little Richardson arm. The average width of the stream channel is about 40 feet on both arms.

The lake is 400 feet wide near the dam and reaches a maximum width of 875 feet in the Little Richardson Creek arm a short distance above the junction of the two arms. In general, however, the width decreases gradually from the dam to the heads of backwater. A dense growth of alder and willow flanks the entire shore line and affords efficient protection against wave erosion and the lakeward transportation of debris from eroding valley walls.

Area of drainage basin: Approximately 50.5 square miles as planimetered from the soil map of Union County.[2] Drainage divides were traced and checked by field observations.

General character of drainage basin.

Geology.--The drainage area of Lake Lee lies in the southeastern part of the so-called "Carolina Slate Belt" of the Piedmont Uplands. Field reconnaissance indicated that the predominant formation is an extremely fine-grained metamorphosed sedimentary rock probably composed of both water-laid and aeolian material, and consisting of mixtures of volcanic ash and landwaste. A small amount of arkose is interbedded. This formation has been called the "Monroe slate," and is believed by some geologists to represent a separate and distinct series within the "Carolina slates," and by others to represent only one facies of the larger series. For field use distinctions can readily be made between the bedded Monroe slate material, with its shallow overburden, and the Carolina slate material, consisting in the main of altered volcanic flows, breccias, and tuffs overlain by a thicker residual soil mantle. Large areas within the Little Richardson Creek drainage basin and smaller and more scattered areas in the Big Richardson Creek drainage basin are underlain by Monroe slate. The Carolina slate areas are generally smaller but occur widely over the drainage basin and tend to predominate along the southern and western divide. These so-called

[2]Derrick, B. B., and Perkins, S. O. Soil Survey of Union County, North Carolina. U. S. Dept. Agr., Bur. Soils Field Oper. 1914, 1916.

"slates" have been considered pre-Cambrian but their age is now in dispute. They are non-fossiliferous. Quartz veins, probably of Carboniferous age, and diabase dikes of Triassic age, are present in the country rock in varying, but generally small, amounts.

Soils.--Both the Monroe and the Carolina slates weather to form fine-textured soils, generally silt loams. The principal soils and their relative extent, as planimetered from the county soil map, are given in table 1.

Table 1.--Soils of the Lake Lee drainage area

Soil series and type	Proportionate area		
	Little Richardson drainage area	Big Richardson drainage area	Total drainage area
	Percent	Percent	Percent
Georgeville:			
Slate loam...............	0.75	5.67	4.29
Gravelly silt loam......	1.95	8.27	6.50
Silt loam...............	15.42	31.18	26.77
Silty clay loam.........	.75	.56	.61
Total.................	18.87	45.68	38.17
Alamance:			
Slate loam...............	13.46	3.07	5.65
Gravelly silt loam......	6.54	2.83	3.87
Silt loam...............	54.66	42.17	46.38
Total.................	74.66	48.07	55.90
Iredell:			
Loam....................	.75	1.52	1.30
Bottom-land soils:			
Congaree silt loam......	2.86	3.82	3.18
Wehadkee silt loam......	2.86	.91	1.45
Total.................	5.72	4.73	4.63
Total soils.............	100.00	100.00	100.00

Owing to improvements in soil nomenclature since the Union County soil map was published, table 1 is subject to some change. The textural classifications, however, are applicable. Remapping of about 18 percent of the drainage area has indicated that approximately two-thirds of the soil previously mapped as Georgeville would probably be termed Herndon under the present classification.[3] Several additional soil types, namely, the Meadow, Altavista, and Powcog series, have been delineated in the area in recent mapping by the local Soil Conservation Service unit.

Field reconnaissance indicated that practically all the soils originally mapped as slate loams and gravelly silt loams, of both the Georgeville and Alamance series, as well as a considerable proportion of those mapped as silt loams, are Monroe slate soils as opposed to Carolina slate types. These Monroe type soils are readily distinguishable by the shallowness of the soil profile and by their droughty nature, a reflection of the much more effective underdrainage on the Monroe slate areas. A fairly high percentage (10 to 30 percent) of slate pebbles and fragments apparently render these soils more open and thus less susceptible to erosion. Locally, about the same effect has been produced by the weathering of quartz veins.

The predominance of fine-grained soils is emphasized by table 2, which gives the mechanical analyses of 6 representative samples. The sand fraction, including all material coarser than 0.05 mm., consists mainly of fine sand but includes a small amount of relatively large granules or pebbles or parent material.

The colums showing median diameters and percentage of material less than 0.02 mm. (20 microns), are included here to indicate qualitatively the degree of susceptibility to transportation by water. To a large extent the mechanical composition and median grain size is an important factor in determining the proportion of erosional debris from a given drainage area that will be deposited close to the source and the part that will tend to remain in suspension for long distances. The fine-grained texture of the soils favors a relatively high net loss from the watershed, other factors being equal.

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[3] This revision in soil classification and the following estimates on erosion conditions and land use were obtained mainly from the files of the local Soil Conservation Service C.C.C. camp. They are based on detailed conservation surveys of about 23,000 acres of farm land under agreement within and adjacent to the Lake Lee drainage area. Minor readjustments of these data to make them applicable to the area concerned were based on rather detailed reconnaissance study.

Table 2.--Mechanical composition of some typical soils of the Lake Lee drainage area

Soil series and horizon	Sand (>0.05 mm.)	Silt (0.05 to 0.005 mm.)	Clay (<0.005 mm.)	Median diameter	Less than 0.02 mm.
	Percent	Percent	Percent	Mm.	Percent
Alamance (A and upper B)....	14.4	72.1	13.5	0.0185	54.0
Georgeville (A and upper B)....	11.2	44.3	44.5	.0074	68.8
Herndon (A and upper B)....	13.0	56.0	31.0	.0117	66.0
Alamance (composite of total A and B).....	29.2	54.0	16.8	.0240	44.5
Alamance (composite of A and middle and upper B)	22.0	60.0	18.0	.0165	57.5
Alamance (middle and upper B)	14.0	42.5	43.5	.0080	67.0

Erosion conditions.--Moderately severe sheet erosion (loss of 50-75 percent of topsoil) has occurred on about 45 percent of the drainage area and moderate sheet erosion (loss of 25-50 percent of topsoil) on an additional 35 percent of the area. Occasional to frequent gullies, predominantly shallow, have developed on about 23 percent of the area. The following tabulation summarizes erosion conditions in the drainage basin in terms of the estimated proportionate area in each erosion class.

Erosion class:[1]	Percent[2]
Recent accumulation	7
Slight sheet erosion	10
Moderate sheet erosion	35
Moderate sheet erosion with frequent gullies	2
Moderately severe sheet erosion	25
Moderately severe sheet erosion with occasional gullies	20
Severe sheet erosion with occasional gullies	1
Total drainage area	100

[1]The erosion classes are defined as follows: Slight sheet erosion, less than 25 percent topsoil removed; moderate sheet erosion 25 to 50 percent topsoil removed; moderately severe sheet erosion 50 to 75 percent topsoil removed; severe sheet erosion, more than 75 percent of topsoil removed; occasional gullies, 1 to 3 per acre; and frequent gullies, more than 3 per acre.
[2]See footnote 3, p. 7.

Typical gullies in the area are linear in outline, and generally shallow, V-shaped, and narrow in cross section. These features are due in the main to the shallow depths at which resistant bedrock is encountered. Depths generally do not exceed 3 to 4 feet, only locally reaching 6 to 8 feet.

The distinction between erosion conditions on the Monroe and Carolina slate soils are readily apparent from field observation. Comparatively little severe sheet erosion and almost no severe gullying occur on the Monroe slate area.

Land use.--About 46 percent of the drainage area is in forest, generally second growth, and 54 percent is cleared. Land under cultivation covers 44 percent of the area. The remaining cleared land is idle or pasture. Approximately 20 percent of the forest land is also pastured. The pastured land makes up about 9 percent of the total area. Urban areas make up about 1 percent of the drainage basin.

The Lake Lee drainage area has never been subjected to the one-crop (cotton) system of farming to the same extent as have other parts of the Piedmont in which this system has seriously depleted soil resources. Corn, grain, and sweet potatoes have always been important crops in the area. In recent years, with the introduction of more efficient systems of rotation and the

discovery of the adaptability of the land to soil-building crops, much improvement in the quality of the soils has taken place. The principal crops grown in 1938 and their proportionate areas are shown in the following tabulation:

Crop:	Percent[1]
Small grain and lespedeza, or lespedeza alone.......	40
Cotton..	27
Corn..	22
Others..	11
Total area..	100

[1]See footnote 3, p. 7.

No significant differences in land use exist between the Big Richardson and Little Richardson drainage areas. The Big Richardson drainage area is 55 percent cleared and 45 percent wooded, whereas the Little Richardson area is 52 percent cleared and 48 percent wooded. Land use alone then, does not account for the differences in sedimentation on the two arms of the reservoir.

Mean annual rainfall.

Records of the cooperative United States Weather Bureau station, located about 1 mile east of Lake Lee, show a mean annual rainfall of 46.57 inches for the period 1894-1937. The average during the life of the lake (1927-1938) was 46.17 inches.

August is the month of greatest rainfall, with an average of 5.46 inches, and November is the month of least rainfall, with an average of 2.00 inches.

History of storage.

Since the reservoir was constructed adequate storage has been available to supply the city's needs. Normal inflow is sufficient to keep the water level above spillway crest on an average of 9 months out of the year. The estimated normal discharge over the spillway during this 9-month period is approximately 47 second-feet. The maximum discharge during the life of the reservoir was 5,400 second-feet. During occasional periods low inflow has caused the water surface to drop as much as 2 feet below spillway crest. The daily draft on the reservoir has ranged from 225,000 gallons to 650,000 gallons, with an average of 365,700 gallons.

The 36-inch "blow-off" valve previously mentioned has been opened on an average of 4 times a year for periods ranging from 24 to 103 hours. It is opened during flood-flows, usually following heavy rains and preceding the actual rise of the lake level, although occasionally coincident with the rise. The calculated discharge of this valve is approximately 200 second-feet.

The turbidity of the lake waters, as measured at the filter plant, has averaged 475 parts per million for the period March 1927 to April 1938. The highest average turbidity occurs in August, and the lowest in November. These occurrences coincide with the periods of maximum and minimum rainfall. During the period of record the turbidity has ranged from 14 to 8,000 parts per million. Considerable difficulty is encountered in desilting the water for city consumption, owing to the extreme fineness of the suspended material.

METHOD OF SURVEY

Water and sediment volumes in Lake Lee were determined by the range method of survey.[4] A horizontal-control system of 28 points was established by plane-table triangulation from a measured base line 580 feet long extending across the dam. This triangulation network was carried up each branch to points where the narrow widths of the branches prohibited further progress by this method. Beyond these points, two checked stadia traverses of 6 points each were extended to the heads of backwater. From this horizontal-control system the shore line at spillway level was mapped by plane table and telescopic alidade on a scale of 1 inch to 200 feet. For the measurement of sediment thickness and water depth 28 ranges were established across the reservoir at suitable positions. All range ends and important triangulation points were permanently marked with 3/4-inch iron pipe embedded in concrete. The survey numbers were stamped on the pipes, whose tops protruded approximately 6 inches above ground surface.

Soundings and direct measurements of sediment thickness were made with 6- and 10-foot silt-sampling spuds. Very little difficulty was experienced in distinguishing lake sediment from the underlying valley soils, owing to excellent contrasts in color, degree of compaction, and texture, as well as to the common presence of a well-defined humus zone marking an old, pre-lake soil underlying the lake sediment. The flood-plain sediments underlying

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[4]Eakin, H. M. Silting of Reservoirs. U. S. Dept. Agr. Tech. Bull. 524: 25-28, 129-135. 1936

the lake deposit are distinctly coarser and more compact than the lake sediment, consisting mainly of coarse silt with occasional grains of sand and gravel included. The older material ranges from greenish gray or gray to grayish brown, and generally is darker than the lake sediment. A layer of highly organic soil with rootlets forms the upper horizon of the flood-plain material at many places. In the submerged channel the pre-lake deposits are coarse, angular sand and gravel consisting of vein quartz and fragments of "slate." The normal pre-lake material on the submerged valley slopes is a gritty clay loam ranging in color from buff to reddish brown.

Eight samples of lake sediment were taken from representative parts of the lake with the 1 1/2-inch tubular sampler previously described.[5] All samples were obtained in 1 1/2-inch detachable iron pipe nipples 4 inches long. The nipples containing the sediment were removed from the sampler immediately after being withdrawn from the lake and capped with threaded, airtight, iron covers for shipment to the laboratory. In addition six samples of representative topsoils of the drainage area were collected for mechanical analysis.

SEDIMENT DEPOSITS

Character of Sediment

The sediment in Lake Lee has a small textural range, from clay to coarse silt. Buff to greenish-buff colors predominate. The organic content is low except in the upper reaches of the lake, where a considerable quantity of leaves is included in the sediment. The upper part of the deposit generally is not very compact. The sediment varies in vertical sequence from loose, "soupy" material of high porosity to moderately compacted material near the base of the deposits. Eight samples from various parts of the lake were found to have porosities averaging 62.0 percent and ranging from 55.7 to 64.3 percent. The samples generally were taken from intermediate depths in the deposit and are probably fairly representative of the complete section.

Volume weights were based on determinations of the moisture content and dry weights of small representative quantities of each

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[5]Connaughton, Mark P., and Hough, J. L. Advance Report on the Sedimentation Survey of Burlington Reservoir, Burlington, North Carolina, U. S. Soil Conserv. Serv. SCS-SS-28: 12. 1939 (Mimeographed.)

sample. The density of the solid sediment was assumed to be the same as that of quartz, 165 pounds per cubic foot.

The locations, depths, thickness of deposit, and weights per cubic foot of the sediment samples are given in table 3.

Table 3.--Sediment samples from Lake Lee

Sample No.	Location	Water depth	Sediment thickness	Dry weight per cu.ft.
		Feet	Feet	Pounds
	Lower basin			
S5....	Range R1-R2, 300 feet from R1	19	5.5	62.8
S6....	Range R5-R6, 150 feet from R5	16	5.0	60.5
	Big Richardson arm			
S7....	Range R9-R10, 250 feet from R9	14	4.5	59.2
S8....	Range R14-R15, 250 feet from R15	9	7.0	58.9
S9....	Range R21-R22, 100 feet from R21	8	1.0	59.9
	Little Richardson arm			
S10...	Range R31-R32, 75 feet from R31	10	3.0	61.2
S11...	Range R37-R38, 50 feet from R37	8	2.5	65.7
S12...	Range R41-R42, 175 feet from R41	5	2.0	73.1
Average................................				62.66
Weighted Average[1]........................				61.77

[1]Weighted average, based on volume of total sediment within each section.

Mechanical analyses of the eight sediment samples are given in table 4. Analyses of the silt-clay fractions were made by the pipette method, and are believed to be of a high degree of accuracy. The sand fractions, including all material coarser than 0.05 mm. in diameter, consist almost entirely of very fine to fine sand.

Table 4.--Mechanical composition of sediment samples from Lake Lee

Sample No.	Sand (0.05 mm.)	Silt (0.05 to 0.005 mm.)	Clay (0.005 mm.)	Median diameter	Less than 20 microns (0.02 mm.)
	Percent	Percent	Percent	Mm.	Percent
S5..............	2.7	33.5	63.8	0.0032	95.5
S6..............	1.7	30.1	68.2	.0030	96.0
S7..............	2.0	40.2	57.8	.0039	92.0
S8..............	2.4	53.0	44.6	.0060	86.6
S9..............	2.4	48.1	49.5	.0051	91.3
S10..............	1.6	49.4	49.0	.0054	90.0
S11..............	1.5	50.3	48.2	.0053	91.7
S12..............	2.3	63.2	34.5	.0082	85.0

As shown by the analyses, the principal constituents of the reservoir sediment in relative order of abundance are: (1) Clay, (2) silt, and (3) sand. The median diameters in each case are very close to the border line between silt and clay. Texturally all the samples would be classified as clayey silts or silty clays, depending on the classification system used. The predominance of material less than 20 microns in diameter is striking, in that 20 microns marks the generally accepted upper limit of material of sufficient fineness to be deposited very slowly from suspension even in very slow currents, such as might be due to wind drift or to density currents. The analyses indicate a very slight increase in average grain size from the dam to the heads of both branches of the reservoir.

The two samples of sediment from the lower basin (S5 and S6), appear to be more closely related in mechanical composition to the sediment of Big Richardson arm (samples S7, S8, and S9) than to that of the Little Richardson arm (samples S10, S11, and S12). In general, it appears that the average median diameter of the sediment is somewhat higher in the Little Richardson arm than in the Big Richardson arm.

Distribution of Sediment

The volumetric distribution of sediment in Lake Lee is illustrated graphically in figure 3, which shows the variations in the original cross-sectional area and in the cross-sectional area of sediment on all ranges crossing the main streams. Since the cross-sectional area of sediment is a function of sediment thicknesses and lake widths, the average thickness of the sediment and the

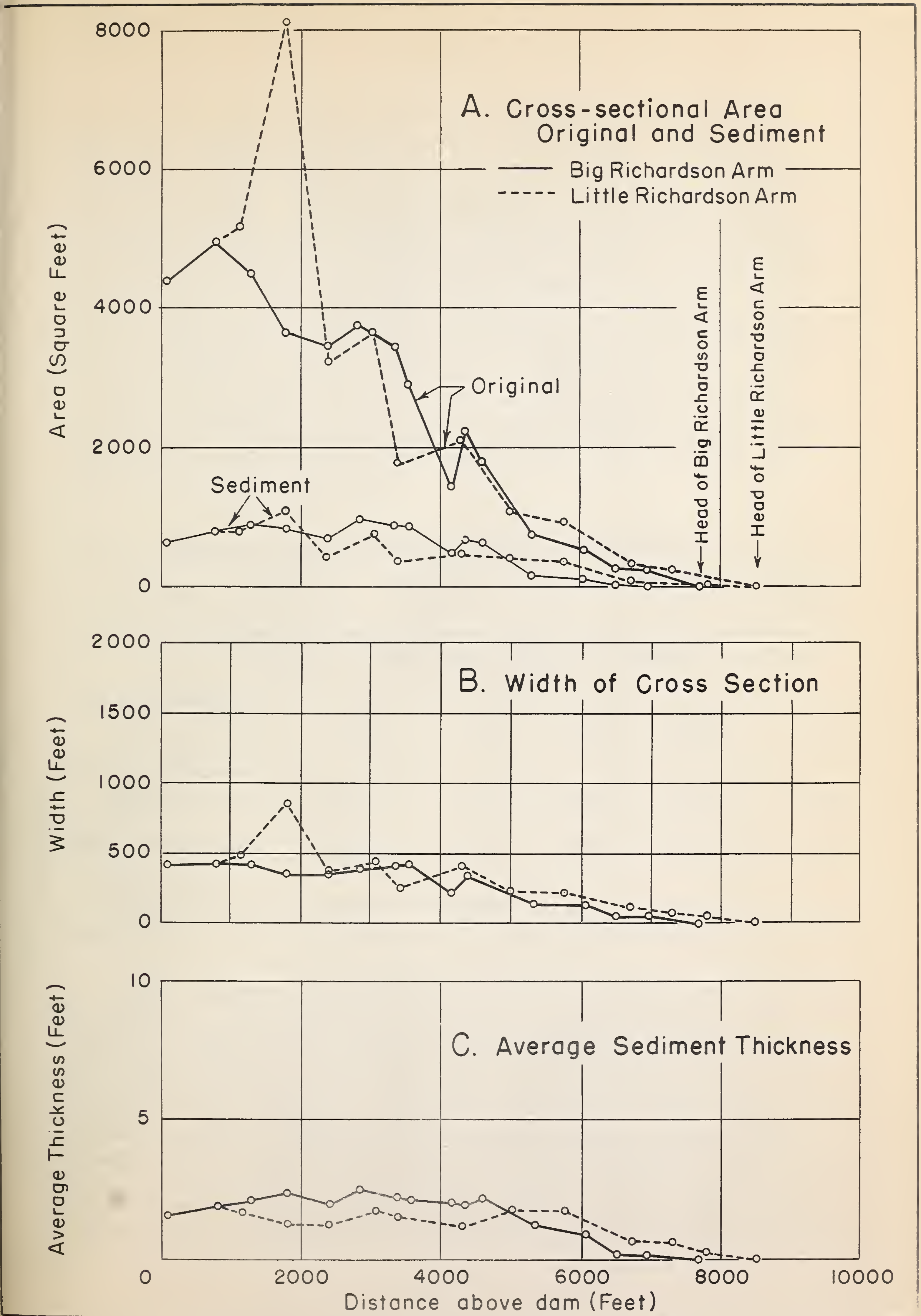

Figure 3.– Longitudinal distribution of sediment in Lake Lee, Monroe, N.C.

width of the lake on each range are also shown graphically so that the relative importance of each may be seen. Figure 3 indicates (1) the proportionate reduction in cross-sectional area is greatest about midway up each arm, (2) the cross-sectional area of sediment, while somewhat variable on successive ranges, is greater in the lower reaches of the lake, and (3) the average thickness of sediment is fairly constant at about 2 feet over all the lake except the upper half-mile of each arm, in which it decreases more or less gradually to the heads of backwater. All these points tend to emphasize the absence of any tendency toward delta formation. The distribution of sediment is further illustrated by table 5, which shows that the Big Richardson arm has accumulated a larger volume of sediment, has a greater average sediment thickness, and has lost a higher proportion of its original storage capacity than either the Little Richardson arm or the lower basin below the forks.

Table 5.--Distribution of sediment in Lake Lee

Section	Original capacity	Sediment volume	Capacity loss	Surface area	Average sediment thickness
	Acre-feet	Acre-feet	Percent	Acres	Feet
Big Richardson arm.........	296	73	24.6	39.3	1.9
Little Richardson arm.....	362	69	19.1	52.5	1.3
Lower basin...	163	27	16.5	13.7	2.0
Total reservoir......	821	169	20.6	105.5	1.6

The lateral distribution of sediment in various parts of the reservoir is illustrated by the series of representative cross sections in figure 4, even though all the cross sections shown are on the Big Richardson arm. Figure 4A is representative of the uppermost four ranges on each arm. Here the sediment blanket is thickest outside of the channel, a condition resulting from the capacity of flood currents to transport the incoming sediment through these reaches and to scour the channel bed. As the greatest velocity of such currents occurs in the channel, major deposition takes place in slack-water areas outside of the channel. In the next section of the basin, sedimentation has resulted in a general smoothing out

of original irregularities (fig. 4B), a feature generally characteristic of the several ranges immediately downstream from those represented by figure 4A. Here the greatest thicknesses occur within the channel, although some heavy deposits of varying thickness occur off to the sides, not only adjacent to the channel but at some distance from it. Such a distribution might be expected to result from a low-velocity current, perhaps generally concentrated in the channel but occasionally (during flood flows) extending over the flood-plain areas. Figure 4C illustrates the tendency toward concentration of sediment in and immediately adjacent to the channel. This distribution is characteristic between ranges R14-R15 and R5-R6 on the Big Richardson arm and between ranges R37-R38 and R3-R5 on the Little Richardson arm. Since currents through these reaches are necessarily of relatively low velocity they are not so effective in transporting sediment, and deposition predominates in the channel, but the zone covered by such currents should show greater accumulation than do the areas off to the side where there is less sediment influx. Figure 4D illustrates a special case of this distribution, in which sediment is thicker on the right bank of the submerged channel. The close resemblance of the profile, thus created, to natural levees formed by flood flows in normal alluvial valleys is striking. As compared with original natural stream levees, illustrated by the original profile in figure 4A, it is evident that this deeply submerged type of natural levee differs only in that its back slope is much more gentle and its relative height is much less. The probable explanation of this type of natural levee will be brought out in the general discussion to follow. Figure 4C illustrates the characteristic sediment distribution on the two ranges below the confluence of the two arms. Here the sediment thicknesses are remarkably even over the submerged flood plain and are disproportionately greater within the submerged channel.

<u>Factors involved in sediment distribution</u>.--Of the multiplicity of factors involved in sediment distribution within a reservoir, it is evident that character and distribution of currents and mechanical composition of the incoming stream loads are dominant.

Current action through a reservoir is, of course, directly related to the shape and character of the reservoir basin, i.e., to the degree of sinuosity, to the bottom gradient, and to variations in width and cross-sectional area. The normal tendency of current action is toward a diminution of velocity from the head of a reservoir toward the dam. The variation in the rate of diminution is dependent on the variations of factors involved in the shape and character of the basin. The tendency towards progressive diminution of current velocity through the reservoir is reflected in the variations in mechanical composition of the sediment

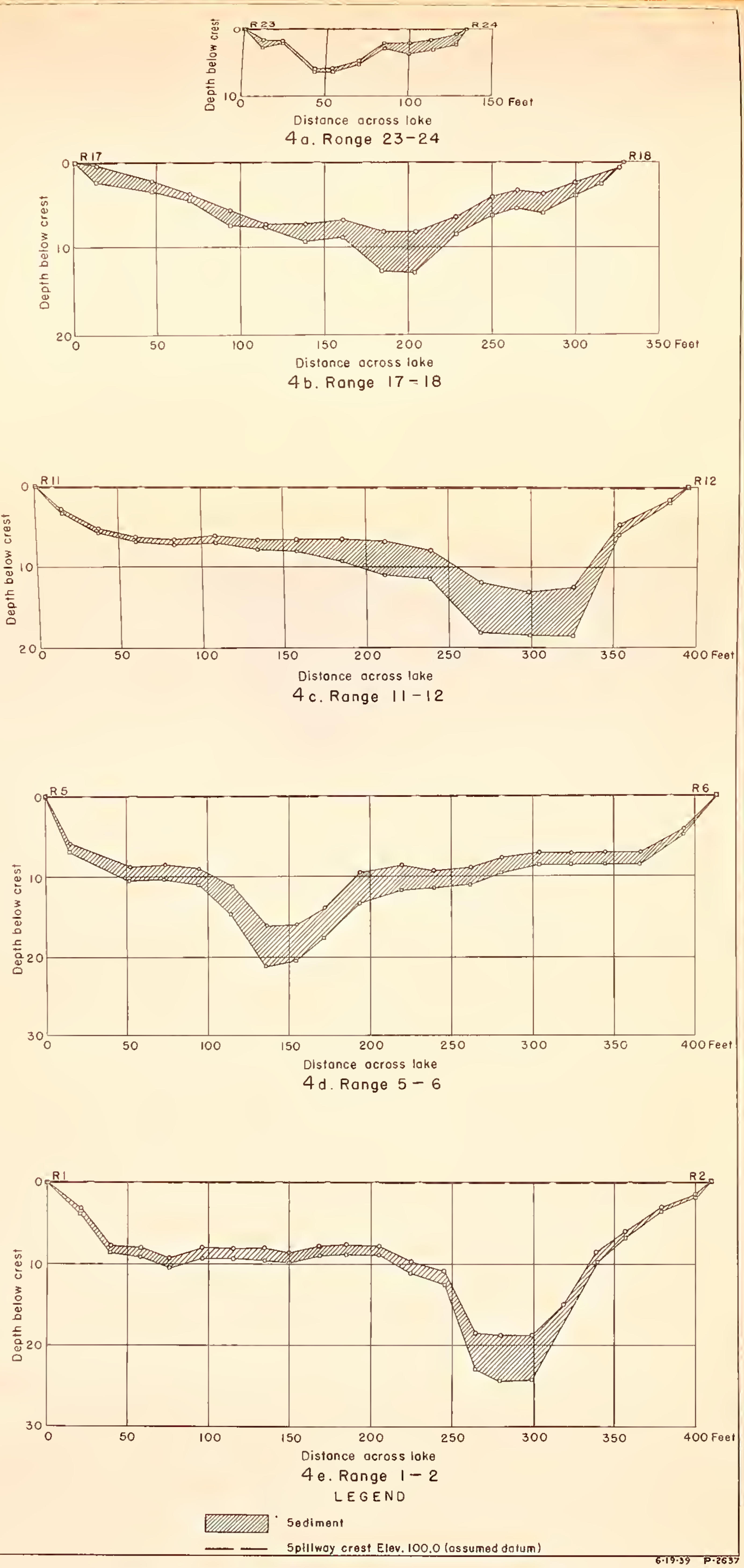

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Figure 4.—Representative Cross Sections of Lake Lee, Monroe, N.C.

deposited. Coarser-textured material is deposited at the first slackening of the current and progressively finer sediment is deposited downstream.

In Lake Lee the gradation in grain size of deposited material from the head of backwater to the dam is evident, even though it is restricted to a slight textural range and is somewhat irregular. The almost total absence of coarse material in the incoming stream load is directly responsible for the lack of a definite delta zone. Longitudinal and lateral irregularities in sediment volumes are in accordance with anticipated current variations. Thus, reaches of comparatively steep gradient have accumulated less sediment than reaches of very flat or negative gradients, straight reaches have accumulated more sediment than reaches on bends, and narrow reaches have accumulated less sediment than wider reaches. The action of density currents or "underflows" (the process by which stream waters of relatively high density, due generally to sediment content, tend to burrow under or flow beneath lake waters of a lower density) is believed to be relatively important in the lower reaches of Lake Lee. A well-defined occurrence of such an underflow phenomenon was observed in the lake during the sedimentation survey.[6]

Underflow.--During the night of June 7-8, 1938, nearly an inch of rain fell in the drainage area of Lake Lee (0.97 inch was recorded at the local United States Weather Bureau station, 1 mile east of the lake). The greater part of this precipitation occurred within an hour around midnight. At about 8:00 a.m. marked underflow was observed at the dam. Highly turbid waters were being vented through the 36-inch "blow-off" valve in the base of the dam, while the surface waters washing over the spillway were relatively clear. Investigation of the headwater reaches on both arms revealed that the highly turbid, sediment-laden stream waters had flowed about 1,500 feet down the lake before sinking beneath the clear lake waters. Both arms of the lake are narrow in the upper reaches and the turbid water extended from shore to shore. The surface boundary between turbid and clear water at the points where sinking occurred (150 feet above range R23-R24 on the Big Richardson arm and 200 feet above R45-R46 on the Little Richardson arm) was sharp, forming a clearly marked line convex downstream with maximum convexity over the channel. A considerable amount of floating debris, apparently skimmed off the incoming water by the wedge of lake water, extended from this line 50 feet or more downstream. A temperature difference between the two water masses was

[6] Hough, J. L. Underflow in Lake Lee, North Carolina. Civ. Engin. Vol. 9, No. 1, pp. 36-37, January 1939.

sufficiently great to be readily distinguishable with the hand, the inflowing water being colder. The turbulent nature of the incoming water mass was evidenced by the many miniature swirls and boils occurring at the surface and clearly outlined by the suspended sediment. Where the underflowing mass was buried beneath only a few inches of clear water, these swirls were found to terminate abruptly at the upper surface of the turbid water, so that apparently only a negligible amount of the suspended load was diffused into the overlying clear lake water. The submerged plane of contact between the lower turbid mass and the upper clear water was observed to slope gently downstream. At a distance of approximately 100 feet downstream from the surface contact of the two bodies, the colder temperatures could be distinguished at a depth of about 1 foot and turbid water could be raised from this depth by stirring. Between the point of sinking and the dam the turbid mass occurred at successively greater depths. When an oar was inserted in the water and swung sharply toward the surface, the water that was raised was either highly turbid or showed no appreciable difference from the surface water, depending upon the depth to which the oar was inserted; thus indicating that the contact between the two water masses remained sharp. On progressing downstream from the surface line of sinking, it was noted that an apparent discoloration of the lake water, due to reflection of light from the underflowing mass, diminished slowly until at a distance of approximately 1,000 feet downstream no difference was noticeable.

Outboard motor boats on the lake stirred up turbid waters wherever they went, but only small "boils" of the strongly colored water were brought up in the lower part of the lake, indicating the greater depth of the underflow body in that area. The surface line of sinking progressed slowly downstream during the day. On the Big Richardson arm this contact moved a total distance of about 4,200 feet, at an average of about 0.2 foot per second. The rate of movement of this surface contact is probably some function of the volume of water displaced by raising of the upper water mass and discharging over the dam. It was noted that the point of farthest advance of the surface line of underflow on Big Richardson arm coincided with the zone of abrupt termination of highly organic, surface-borne debris.

The run-off from the previous night's rain was undoubtedly denser than the lake water because of its sediment content and its lower temperature. It flowed along the deeper sections of the reservoir (essentially the submerged stream channel) as a sheet-like current, probably depositing sediment as velocities decreased. Such sediment-laden currents, generally confined to the submerged channel but occasionally overlapping the submerged flood plain

during heavy discharge periods, would, through progressive deposition, build up the channel bottom more rapidly than the flood plain. Locally, where the underflow body was of greater cross section than the confining channel, the waters, overlapping on the adjacent flood plain, would be subject to great lateral reduction in velocity and would tend to deposit their sediment load adjacent to the channel as natural levees (fig. 4D).

As an aid to the study of sediment distribution in the lower reaches of the reservoir, graphs were drawn showing the ratio of sediment depth to original water depth. Practically all ranges in the lower reaches showed low sediment-water depth ratios on the submerged flood plain, intermediate ratios within the submerged channels, and high ratios immediately adjacent to the channel. Such a relationship is best explained by distribution mainly through underflow, (1) the lower ratio on the flood plain being a reflection either of occasionally large underflows or of currents dispersed through the entire section, (2) the intermediate ratios in the channel being a reflection of frequently occurring underflows, and (3) the high ratios immediately adjacent to the channel reflecting rapid lateral reductions in underflow velocities, which result in accentuated deposition.

Origin of Sediment

The dominantly silty soils of the drainage area produce large amounts of fine-grained sediment that tends to remain in suspension even in currents of low velocity. The erosional debris therefore tends to move comparatively long distances before deposition.

Widespread sheet erosion on cultivated land is probably the principal source of reservoir sediment. Stream-bank erosion is relatively unimportant, owing to the generally good bank protection provided by dense vegetation. Very little of the bottom land has been cultivated, probably because of the narrow widths available. Even where cleared, these first bottoms are generally in pasture. Only a few minor reaches show the harmful effects of brushing out the stream banks.

Gully erosion is of considerable importance locally within the drainage basin and may furnish an appreciable amount of the reservoir sediment. Although gullies are comparatively shallow, their aggregate volume is considerable. A rather striking feature is the general absence at the mouths of these gullies of alluvial fans such as are normally associated with similar gullies in many parts of the Piedmont. This absence of fans is believed to be due

to the very general lack of coarse material in the erosional debris. The bulk of eroded gully material in the drainage area is probably carried almost immediately into the major drainage channels.

The fairly complete drainage-area reconnaissance indicated that gullies are generally due to artificially concentrated runoff, such as results from improper ditching of existing roads and excessive washing along unprotected reaches of abandoned roads. In only a few cases were gullies found to be due to breaking-over of improperly constructed terraces or erosion of terrace outlets.

The county soil map of 1914 shows an intricate network of roads, whereas recent maps reveal a much smaller mileage of roads, most of which follow different routes than did the older ones. In general, the old roads in this area, with their devious, crooked patterns and lack of maintenance tend to produce more erosion per unit of total land area than do the modern roads. The present era of the automobile, with its demand for the shortest route between given points, and the elimination of steeper grades and sharp curves, has resulted in the abandonment of many long crooked reaches of the old roads. For obvious reasons these abandoned roads, lacking sufficient good soil for rapid natural revegetation or for agricultural use, have been especially subject to the ravages of concentrated erosion. Although in the aggregate these roads probably represent a very minor fraction of the total drainage area, it is believed that they furnish a relatively high proportion of the reservoir sediment.

<u>Comparison of sedimentation conditions on the two arms of Lake Lee</u>.--A comparison of the two main arms of the reservoir with respect to sediment volume (see table 4, p. 14) and drainage area revealed that conditions of sedimentation differ markedly. The Little Richardson arm, with a considerably larger storage capacity and a much smaller drainage area, has trapped nearly as much sediment as the Big Richardson arm. Calculations indicate that the Big Richardson arm contains 2.14 acre-feet of sediment per square mile of drainage area whereas the Little Richardson arm contains 4.26 acre-feet per square mile. These figures are exclusive of the deposits below the forks, which cannot be apportioned between the two arms. These data appear to indicate either that erosion has been much more active in the Little Richardson drainage area than in that of Big Richardson Creek or that a larger proportion of the eroded material has been trapped in the arm. A complete study of the many factors concerned in these differing rates of sedimentation and erosion could not be undertaken, but reconnaissance study has suggested certain explanations.

Erosion and soil data show no significant differences between conditions in the drainage areas feeding the two arms. Two important factors, however, in addition to erosional characteristics, must be considered in relation to contrasts in sedimentation. These are the relative extent of upstream deposition and the extent of bypassing of sediment through the two arms. Field measurements of modern valley deposits above the two arms failed to reveal any outstanding differences in thicknesses in the two drainage systems. Noteworthy distinctions are evident, however, in the relative extent of lands subject to deposition in the two areas. The Little Richardson area contains only 4.7 percent of bottom land subject to deposition, as against 6 percent for the Big Richardson area.

The relative importance of bypassing of sediment through the two arms of the lake is emphasized by the differences in storage capacity-inflow ratio, as measured by the capacity per unit area of watershed. The Little Richardson arm has a storage capacity of 16.1 acre-feet per square mile, as compared with 8.7 acre-feet per square mile for the Big Richardson arm. Because of this condition currents move more slowly through the Little Richardson arm and thus permit the deposition of a greater proportion of the incoming sediment load prior to reaching the junction of the other arm. Further evidence of this condition is the general tendency of the sediment below the forks to correspond more closely, both in mechanical composition and depth of accumulation, to that of the Big Richardson arm. To summarize, the proportionately greater sediment accumulation in the Little Richardson arm is believed to be due, not so much to actual differences in erosional activity, nor to less favorable land use in the drainage area, as to a lesser susceptibility to upstream deposition and to lesser bypassing of sediment actually reaching the lake.

CONCLUSIONS AND RECOMMENDATIONS

A summary of the data of the survey is given in the tabulation on page 23. At the present rate of sedimentation the lake will be completely filled in another 43 years, or after a total life of only 54 years. Although it is expected that the annual rate of storage depletion will decline as the reservoir capacity is progressively reduced and a larger proportion of incoming sediment is carried through the lake, this decline will be balanced by the fact that the useful life of the lake will be ended long before it is completely filled with sediment. As the useful life will probably not exceed the figures given above under existing conditions the advisability of remedial measures is strongly

emphasized. Such measures should be aimed primarily at conservation of the existing storage in the basin. Since the ultimate source of all the sediment is erosion on lands draining into the reservoir, a need for widespread soil conservation measures is indicated. Such measures in this area would have double benefits, to the city water supply on the one hand, and to the land owners on the other, and therefore a double measure of justification. Need for active cooperation of rural and urban, of local, State and Federal interests is strongly indicated. Advice and aid in necessary conservation planning could best be obtained through the supervisors of the Brown Creek Soil Conservation District, of which Union County is a part.

Up to 1938 only 40 landowners in the drainage area, controlling a total acreage of 5,864 acres, or 18.1 percent of the total area, have instituted erosion control measures under cooperative agreements with the local Soil Conservation Service unit. Of the treated land 1,467 acres were in the Little Richardson area, and 4,397 acres were in the Big Richardson area.

The treatment of abandoned roadways, as well as of eroding reaches of modern roadways, through the establishment of lower slopes and better vegetative covering is of importance. Much information is already available on the technique of establishment and maintenance of proper road-erosion control. The rapid application of such control measures would unquestionably be desirable here.

The life of the reservoir can be prolonged to some extent by judicious and frequent use of the "blow-off" valve in the base of the dam. Observations made during the course of the underflow of turbid water on June 8, 1938, indicated that approximately 400 acre-feet of turbid water, carrying about one-half acre-foot (21,800 cubic feet) of suspended sediment, was bypassed through the "blow-off" valve in a 24-hour period, whereas in the same period a much greater volume of clear water was wasted over the spillway. Underflow was observed again on June 10, 1938. Underflows of sediment-laden water are believed to be of frequent occurrence in this reservoir. Unless the outlet in the base of the dam is opened, this turbid water will cause the overlying clear water to rise and pour over the spillway, whereas the sediment load of the turbid mass will be deposited on the lake bottom. If the "blow-off" valve were to be opened whenever the amount of water flowing over the spillway exceeded the capacity of the discharge pipe, i.e., approximately 200 second-feet, an appreciable amount of sediment would be bypassed.

Summary of data on Lake Lee, Monroe, N. C.

	Quantity	Unit
Age[1]	11.1	Years
Watershed area[2]	50.5	Sq. miles
Reservoir:		
Area at spillway stage:		
Original	105.5	Acres
At date of survey	104.8	Acres
Storage capacity to spillway level:		
Original	821	Acre-feet
At date of survey	652	Acre-feet
Capacity per sq. mile of drainage area:[2]		
Original	16.26	Acre-feet
At date of survey	12.91	Acre-feet
Sedimentation:		
Total sediment	169	Acre-feet
Average annual accumulation:		
From entire drainage area	15.2	Acre-feet
Per 100 sq. miles of drainage area[3]	30.3	Acre-feet
Per acre of drainage area:[3]		
By volume	20.59	Cubic feet
By weight[4]	0.64	Ton
Depletion of storage:		
Loss of original capacity:		
Per year	1.85	Percent
To date of survey	20.58	Percent

[1]Storage began April 27, 1927; date of survey, May 23 to June 14, 1938.

[2]Including area of lake.

[3]Excluding area of lake.

[4]Assuming average weight of one cubic foot of silt is 61.8 pounds.

Figure 2

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE
H. H. BENNETT, Chief

MONROE MUNICIPAL RESERVOIR

LAKE LEE

UNION COUNTY
NORTH CAROLINA

SEDIMENTATION SURVEY OF MAY 23 TO JUNE 14, 1938

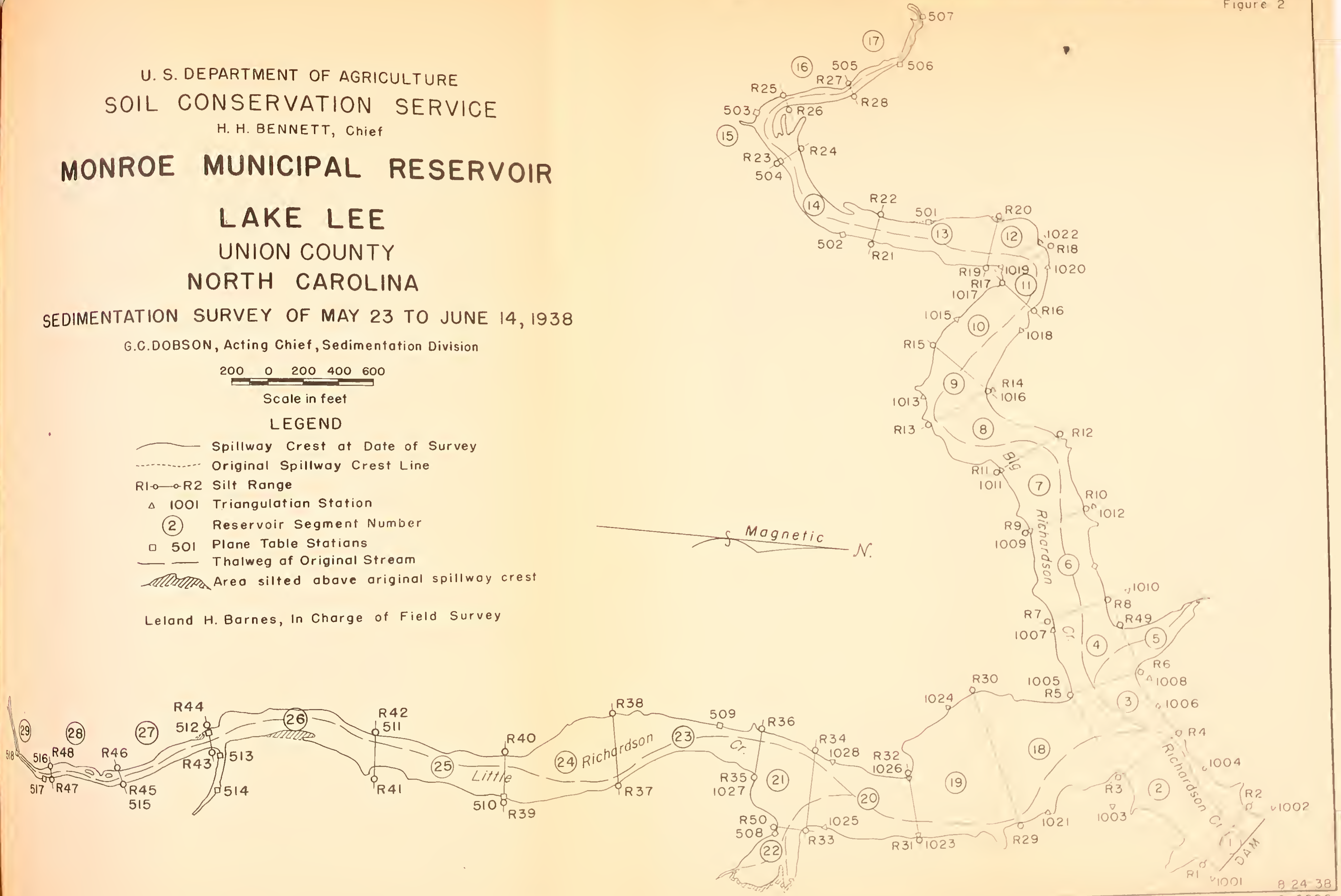
G.C. DOBSON, Acting Chief, Sedimentation Division

200 0 200 400 600
Scale in feet

LEGEND

Spillway Crest at Date of Survey
Original Spillway Crest Line
R1—R2 Silt Range
1001 Triangulation Station
2 Reservoir Segment Number
501 Plane Table Stations
Thalweg of Original Stream
Area silted above original spillway crest

Leland H. Barnes, In Charge of Field Survey



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